obtained between different weather elements of widely separated stations and at disconnected times. The correlation here exceeds nineteen times the amount of the probable error. Other Indian stations show high positive correlations, for example, Bangalore pressure, January to October with Winnipeg winter temperature, $r = +0.43$. In all cases in which the mean monthly pressure departure at Nagpur for January–October equaled or exceeded 20 (1/1000 inch) the winter temperature at Winnipeg had the same sign of departure." The highest India pressure, of 1877, was followed by the mildest winter at Winnipeg. Pressure maximum in India is associated with winter temperature maxima later over an immense part of Canada and the United States.

"The summer and autumn temperature of the western and eastern coasts and likewise of the interior of India show high correlation of like sign to the winter of North America, from the mouth of the St. Lawrence to Montana and Saskatchewan. Here also Winnipeg holds the record.

"The rainfall of India likewise proves of special significance relative to the region around Lake Winnipeg." Though most of India's rainfall comes in June to September, it appeared advantageous to include all the months, January to October. This element shows negative correlation.

By the method of partial correlations these three elements of India were combined into a regression equation, which gave a coefficient of $r = +0.81$ (1875–1920):

$$\Delta t \text{ XII–II Winnipeg} = +0.21\Delta p \text{ I–X Nagpur} + 1.00\Delta t \text{ VI–VII Madras} - 0.10\Delta N \text{ I–X (Jaipur + Lahore)}/2$$

p stands for pressure (thousandths inch), t for temperature (°F.), and N for precipitation (inches). The mean difference between calculated and observed temperature at Winnipeg is but 2.9° F., which is but 52 per cent of the mean winter temperature anomaly of 5.6° F. All cases of calculated departures of 5° or more (15 of the 46 years) have winters of the same sign; and all warm or cold winters 5° or more from normal agree in sign with the calculated departure. In very many cases there is the possibility of a nearly certain forecast; of the 28 cases of calculated departures of 3° or more, 26 winters have the same sign. Calculated and observed departures of any size agree as to sign for the whole 46-year period in 80.4 per cent of the cases.

"In addition to the weather elements of India the winter of Manitoba is effectively influenced by the October air pressure and the October-November temperature at Batavia; both correlations are positive,"

$$r = +0.54 \text{ and } +0.60, \text{ resp., } 1873\text{–}1922$$

The Nile flood shows nearly the same negative correlation with the succeeding winter at Winnipeg as for that of central Europe.

Central Argentine temperature, at Goya, from April to June, is correlated with the Winnipeg winter, $r = +0.52$ (1877–1920). In all cases where Goya temperature was 1.5° C. or more above or below normal (8 years out of 44) the winter in latitude 50° N. and in longitude 100–105° W. had the same sign.

Egyptian pressure in summer, July at Cairo, has a correlation with the following winter at Winnipeg, $r = 0.44$ (1873–1922).

Cold winters in subarctic continental North America are as a rule snowy, and the mild winters deficient in precipitation; thus it is not particularly surprising to find Nagpur pressure, January-October, correlated with Bismarck winter precipitation, $r = -0.50 + 0.07$. Similar values were found for the other stations.

The winters of central Europe are indicated by the same factors as are those of Canada. These are the weather elements of India and of the Sunda Sea in summer and autumn of the Southern Hemisphere; also, here we have again the interaction of Argentine weather in the autumn of the Southern Hemisphere with the monsoon intensity over the northern part of the Indian Ocean. The weather elements of Egypt are functions of the southwest monsoon, not of the Atlantic Ocean. Stronger southwest monsoon in India brings copious rains, with low pressure and relatively cooler weather in India itself. For cold winters the scheme reads:

Canada	*Central Europe*
$-p$ I–X India.	$-p$ I–X India.
$-t$ VI–XI India.	$-t$ VI–XI India.
$+N$ I–X India.	$+N$ VIII–XI India.
$-t$ IV–VII Argentina.	$-t$ IV–VII Argentina.
$-N$ I–VII Argentina.	$-N$ I–VII Argentina.
$+p$ IV–VI Argentina.	$+p$ IV–VI Argentina.
$-p$ VI–VIII Egypt.	$-p$ III–VIII Egypt.
+Nile VII–X Egypt.	+Nile VII–X Egypt.
$-p$ X Java.	$-p$ X Java.
$-t$ X–XI Java.	$-t$ X–XI Java.

THE DAILY MARCH OF TEMPERATURE AND HUMIDITY [1]

551.524 : 551.571

By V. E. SHELFORD

[V. E. Shelford, Vivarium Building, Wright and Healy Streets, Champaign, Ill.]

A study of development of the various stages of the codling moth carried out a few years ago (Shelford, 1927), indicated that the evaluation of rates of development must be based upon a combination of temperature and moisture. These two factors vary roughly reciprocally and are quite inseparable for that reason.

In this study experiments were carried out in great detail on the pupa. For this stage a chart was made showing the rate of development at each combination of temperature and humidity under which the pupa would live and develop. The chart is shown in Figure 1. Rates or velocities are given in developmental units per hour, the developmental unit being the difference in amount of development between a given degree of medial temperature and the amount 1° higher. The total is measured in terms of the total number of hours to complete the stage at several medial temperatures. Lines connect combinations of temperature and moisture giving the same rate. The figures at the right of the curve show the developmental units per hour characteristic of each line. Under average conditions the total (°F. and hour) developmental units required to complete the pupal stage is 6,480. One hour at 75 per cent humidity and 54° F. gives 5 units while one hour at 80 per cent humidity and 89° F. gives 37 units. In preparing this chart, variable temperature experiments were introduced. In these chambers the temperature rose during the forenoon when the sun was shining through the glass roof of the room or when large incandescent lamps were turned on during cloudy days. It fell off in the afternoon and was

[1] Contribution from the Zoological Laboratory of the University of Illinois, No. 355.

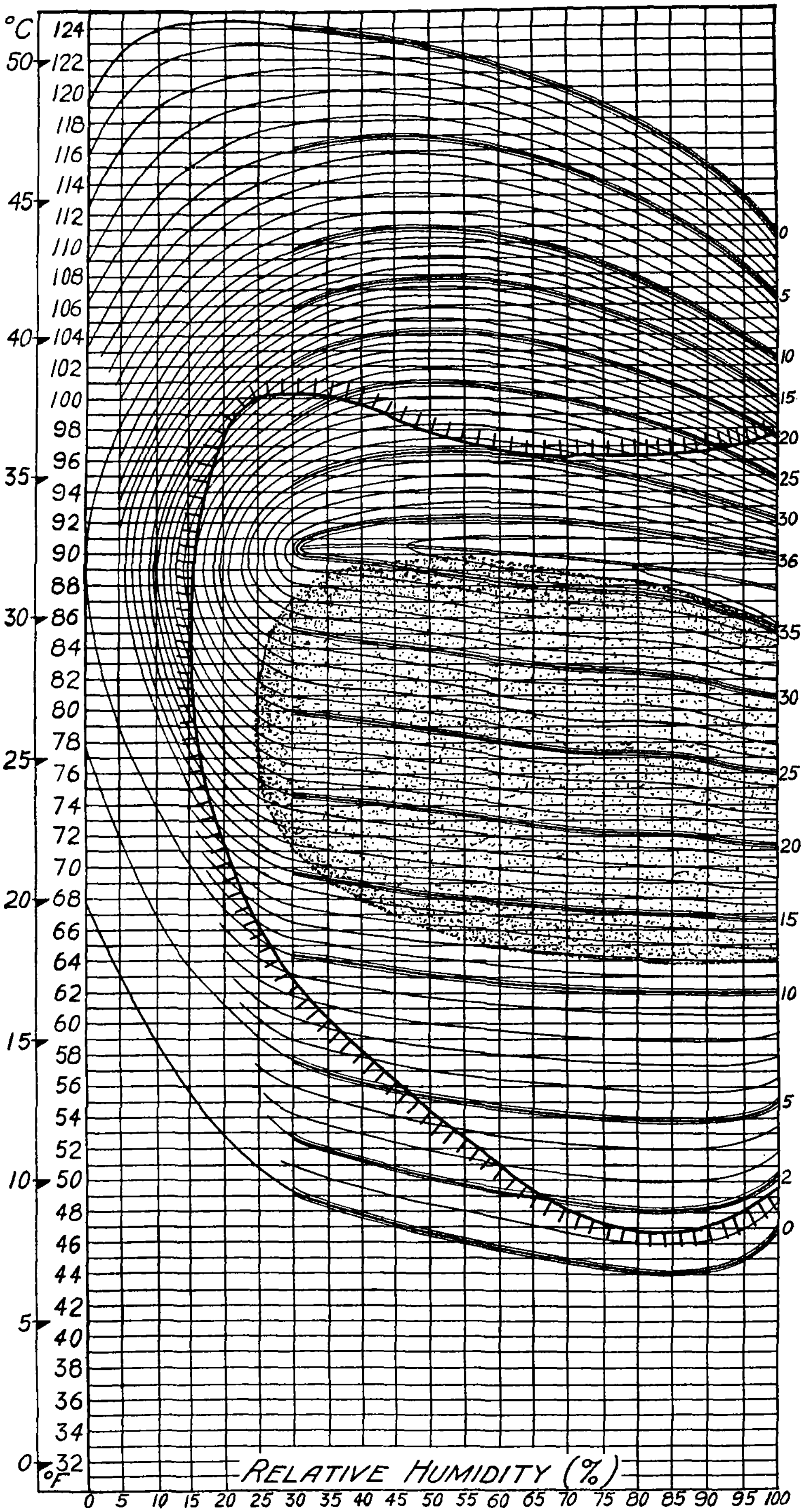

FIGURE 1.—The chart made for the codling moth pupa, in which the curved lines connect temperature and humidity combination in which the rate of development is the same. The figures at the right are the velocities, in developmental units per hour characteristic of the lines opposite. The heavy line indicates the limits of successful constant temperature experiments. Medial temperatures are those within which the laws of the equilateral hyperbola hold good

held constant during the latter part of the night by means of a thermostat which turned on a heater at a fixed minimum. This gave simplified day with a daily march of temperature and humidity similar to that occurring out of doors. These experiments were found to be of the greatest value as they enabled the author to bridge the gap between the constant temperature experiments and the weather conditions. The constant temperature and humidity experiments can not be successfully made outside the limits marked in Figure 1. The variable temperature experiments were used to cover the parts of the chart in which mortality rendered constant temperature experiments impracticable and the values in the parts of the chart depended upon these and comparisons with outdoor conditions.

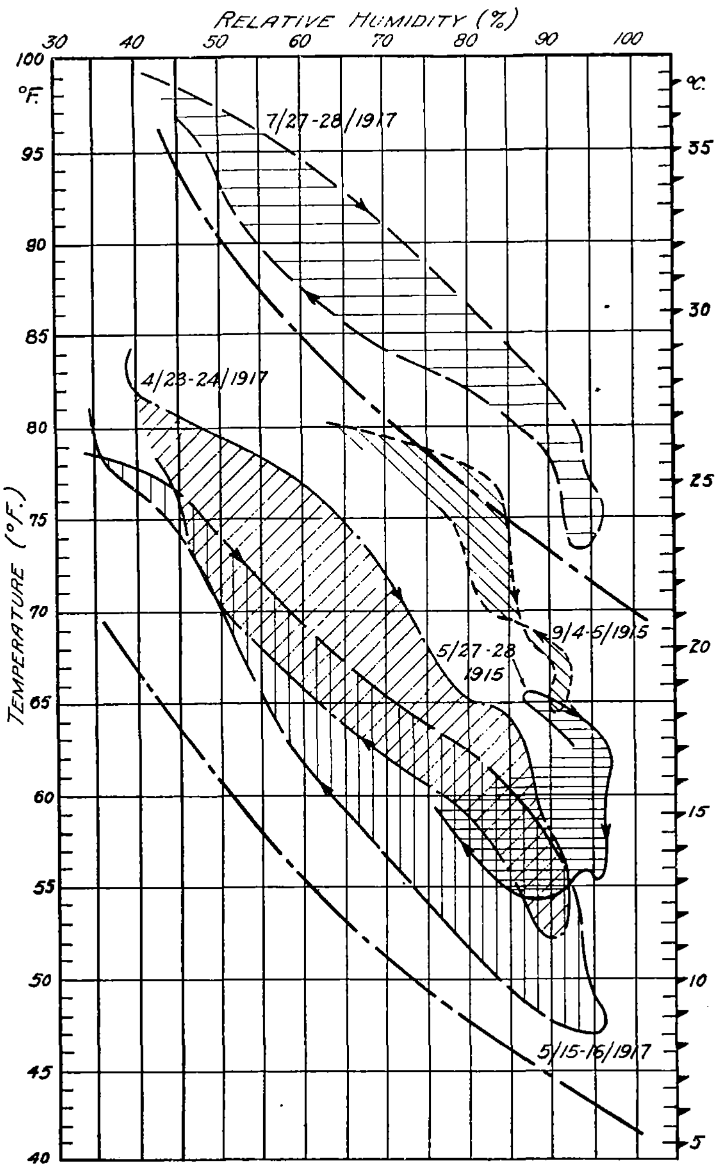

FIGURE 2.—The daily march of temperature and relative humidity on several typical days. May 27-28, 1915, is a rainy day while the others are typical clear days fairly characteristic of the season. The two heavy concave curves show the change in relative humidity which takes place when air is warmed from saturation temperature without the addition of water vapor

The application of this chart in predicting the rate of progress of pupæ toward emergence as moths which will provide eggs and finally larvæ to enter the apples, requires a continuous simultaneous record of temperature and humidity such as may be made with a Friez hygrothermograph. In all cases the relative and actual decrease in velocity of development at high temperatures as well as the relative increase at low temperatures is accounted for when daily march of temperature is taken into account hour by hour. This hourly accounting is absolutely essential to the proper evaluation of temperature results.

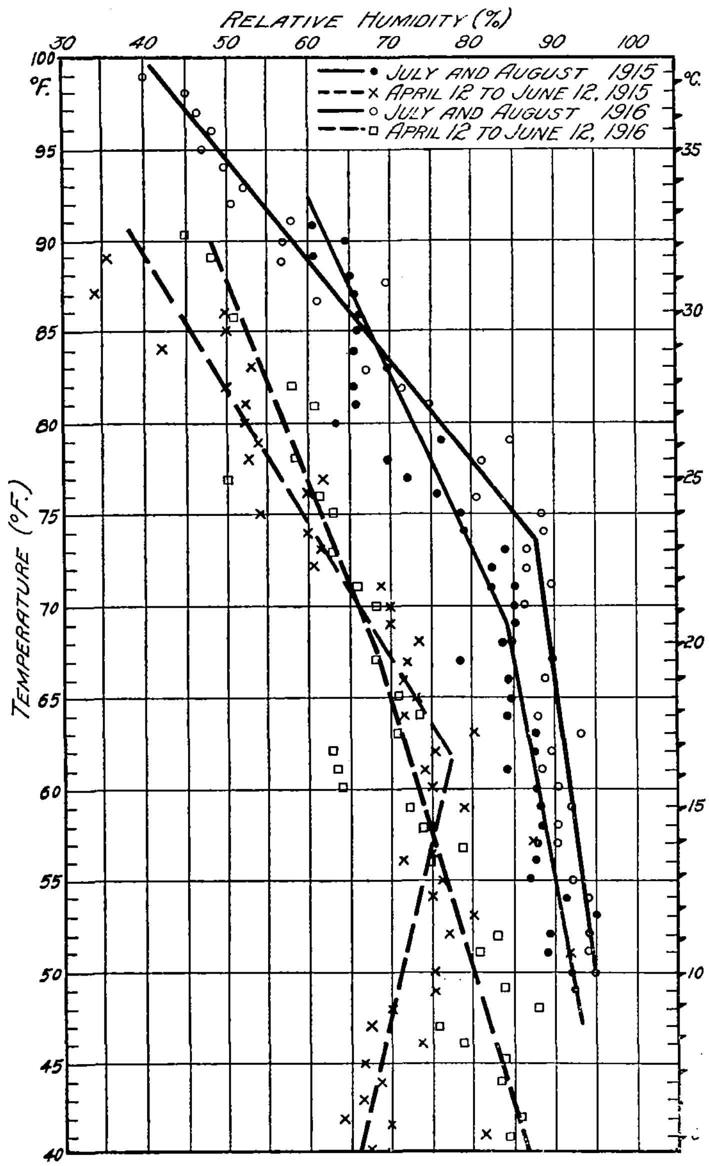

FIGURE 3.—The average humidity at the various temperatures for the periods noted. The differences in different seasons are correlated with rainfall, maximum and minimum temperatures, and (apparently) transparency of the atmosphere which gave rapid rises in the forenoon.

After the chart was completed (Shelford, 1927), it was applied to the three years' data on the codling moth carried out by P. A. Glenn, of the State entomologist's office, at Olney, Ill., 1915, 1916, and 1917. Thousands of readings of temperature and moisture were taken from his hygrothermograph records and used with the chart and checked against the time for known life history stages with a correspondence between prediction and actual known times of appearance hardly to be expected. The most important result, however, grew out of a study of the records in which comparisons of the different years brought out increased length of pupal life following dry winters, etc. Comparison of different seasons in the same year showed marked differences with rising and falling temperature. While the differences due to humidity amount to less than 15 per cent under ordinary weather conditions, differences due to winter rainfall apparently amount to 10 per cent, and those due to rising and falling temperatures appear to amount to as much as 18 per cent. To determine either of the last two, the first must be eliminated. Glenn's Friez hygrothermograph readings of temperature and humidity were taken from the original sheets on the even hours. Such records are essential to the application of such a chart in practical prediction of the time of application sprays. The chart has the advantage of taking into account two factors instead of one factor and of being less likely to fail in years of extreme abundance of the pest, than the simple sum of temperature which can not even take account of the various relative effect of temperature at the higher and lower values.

In connection with this study several other uses for continuous records of temperature and humidity and some general characteristics of the daily march were made out.

Figure 2 shows the daily march of temperature at Olney, Ill. in 1915 and 1917. From 2 p. m. to 12 m. of the following day. In a general way the relative humidity changes much as does air with a fixed amount of humidity when warmed. Some days, as for example, April 23, 1924, show a higher relative humidity as the temperature goes up than does heated air due to evaporation from soil and plants. An occasional summer day, as e. g., July 27, 1928, shows a relative humidity lower than is to be expected at the higher temperatures. Rainy days as May 27, 1928, show a small range of relative humidity.

In preparing for experiments it is necessary to have the average daily march over various portions of the growing season determined to suit the plants or animals being considered. Where constant temperature experiments are to be set up, they should fall on the average daily march at the several temperatures used. The use of several temperatures at a fixed relative humidity is not a desirable method to follow because it greatly increases the number of experiments to be run. The average daily march for various periods was worked out by averaging the relative humidity at each temperature taking a period in the growing season which is of significance for the form being studied (Fig. 3.) This April 12 to June 12 covers the usual period of maximum numbers of codling moths in the pupal stage. The low average humidities for 1915 as compared with 1916, at the low temperatures, are shown by an inspection of the hygrothermograph sheets to be correlated with a sharp rise in temperature during the morning hours, probably due to a clear atmosphere. The months of July and August in 1916 showed considerable difference from 1915 both in temperature and average humidity at the same temperatures. Nineteen-sixteen was a year of extremes.

Experiments should have several years of hygrothermograph records at hand for the locality in which plants and animals are to be studied. The writer has found, however, that the United States Weather Bureau has recently stopped using these instruments quite generally. They should be in service in as many stations as possible because the use of the reciprocally operating factors in combination makes possible the evaluation of other factors. (Shelford 1927 and 1929.)

The scale used in diagrams such as are presented here is the one used in all the two dimension diagrams made in the author's laboratory. They have been based upon 5° C. equals (in actual scale distance) 50 millimeters rain or 20 per cent relative humidity. Accordingly, 9° F. equals (actual scale distance) 2 inches precipitation and 20 per cent humidity. This makes possible the plotting of weather data from either Fahrenheit or centigrade. Diagrams on different scales can not be readily compared without redrawing.

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A TROPICAL CYCLONE IN SOUTHERN CALIFORNIA [1]

551.515 (213) (794)

By DEAN BLAKE

[Weather Bureau Office, San Diego, Calif.]

Receipt of weather maps issued at Mexico City for the period September 10 to 18, 1929, enables us to trace the approximate path taken by the storm that appeared unheralded over extreme southern California on the morning of September 17, and to substantiate the conviction that the abnormal weather conditions that occurred at that time were the result of a tropical cyclone that moved northward along the west coasts of Mexico and Lower California.

On the afternoon of September 16 a remarkably dry, desiccating hot wave, which apparently was moving westward, was reported from the valleys in San Diego County back from the coast. The first word came from El Cajon, about 14 miles inland, where temperatures considerably over 100° were being experienced. As the afternoon advanced, alarmed citizens, who associated the heat with brush fires burning in the hills, telephoned from points progressively nearer the city, and near 4 p. m. temperature contrasts between the downtown sections of San Diego and the surrounding hills became very marked. It was about this time of the day that exceptionally high maxima were registered in the county, El Cajon reporting 111°, Escondido 107°, and Ramona 102°, these temperatures being accompanied by strong easterly winds.

At the station the winds were light to gentle and from the west and northwest, and the relative humidity only slightly below normal. Two miles away, however, strong easterly winds and abnormally low relative humidities were reported, and many people who experienced the change between the two currents commented upon its suddenness and abruptness, the line of demarcation being sharply defined.

It was not until 4 a. m., 12 hours later, that the hot wave finally reached the San Diego station, but when it did the temperature rose suddenly from 70° to 94° in less than 30 minutes, and there was a decrease in the relative humidity to 16 per cent. The maximum temperature for the day, 95°, occurred at 7:30 a. m. after which hour the temperature slowly decreased, due to the increasing cloudiness and later to the rainfall. Although at sundown the night before the sky was cloudless and the relative humidity was 72 per cent, at 8:55 a. m. a sprinkling rain began with a relative humidity of only 38 per

[1] Cf. Hurd, W. E., This REVIEW, vol. 57: 397-8.